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(54) Optic fibre

(57) An optical fibre such as might be used for the transmission of data or as a sensor, is formed of substantially torsion-free material which is twisted during drawing to have a rate of twist per unit length greater than the intrinsic birefringence. The material is torsion-free hence avoiding the torsional stresses which produce circular birefringence but the spinning averages out the stress induced linear birefringence and the form of birefringence. The spinning thus ensures that residual polarisation mode dispersion is reduced to a negligible value. Fig. 1 illustrates one technique for making such fibres; a preform 10 fed into a drawing furnace 13 is spun by a motor 11 to impart the required twist to the fibre 15.

FIG. 1.

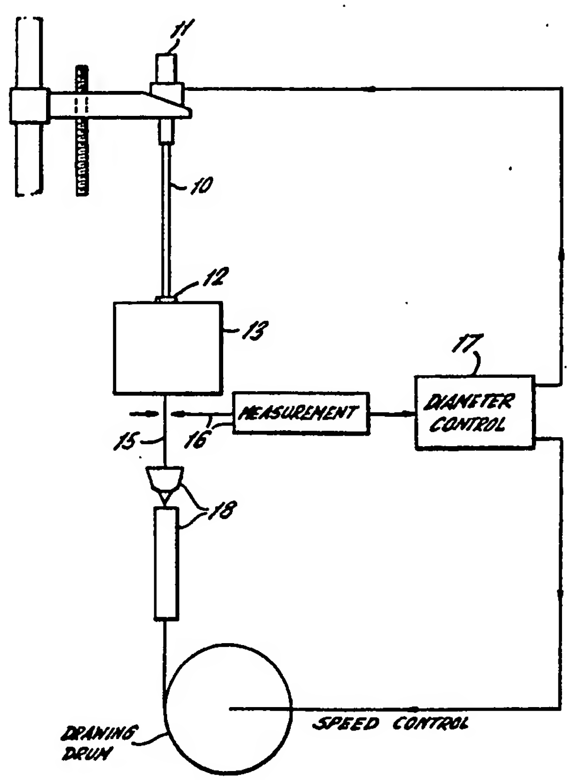

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FIG. 1.

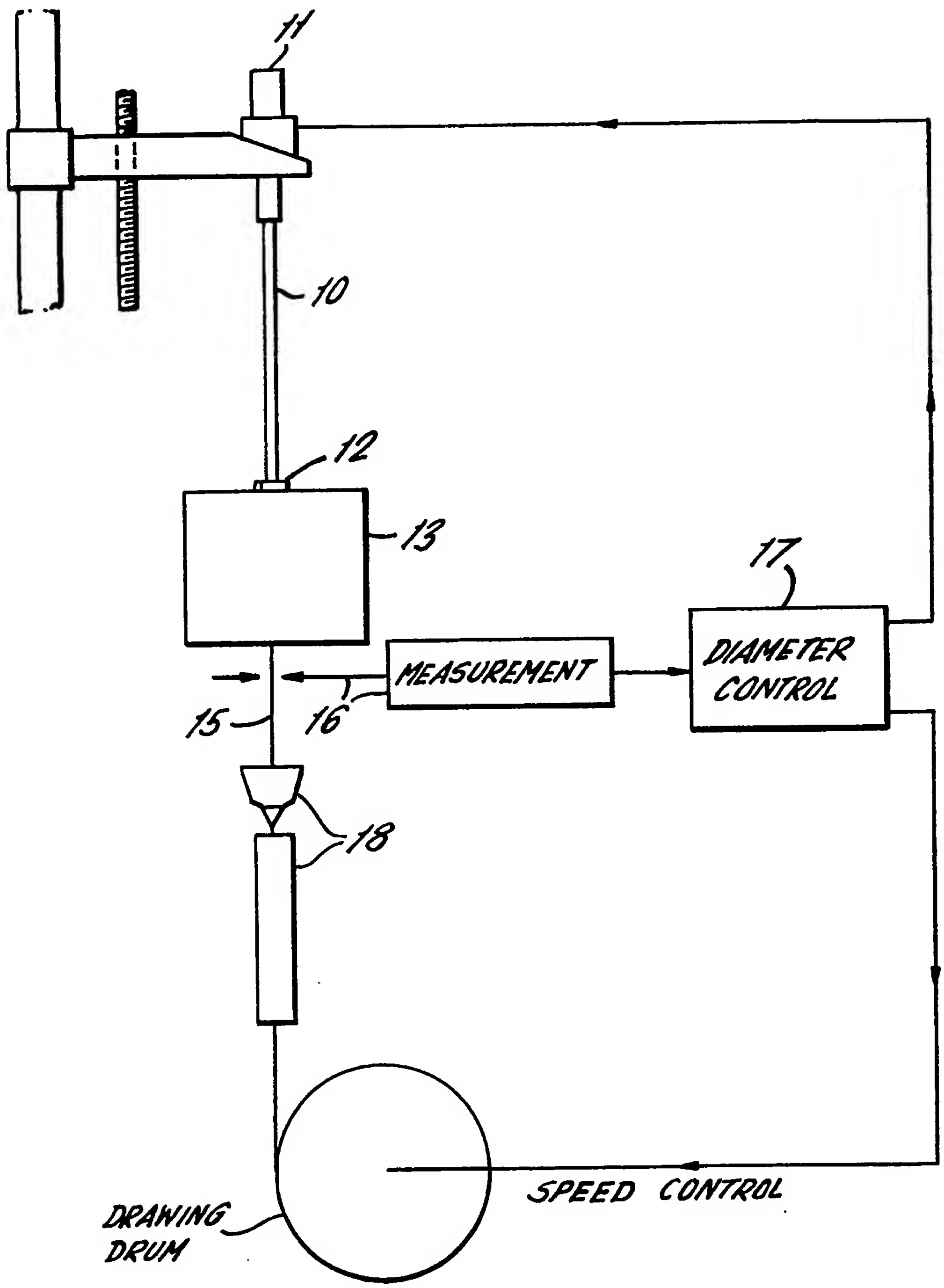
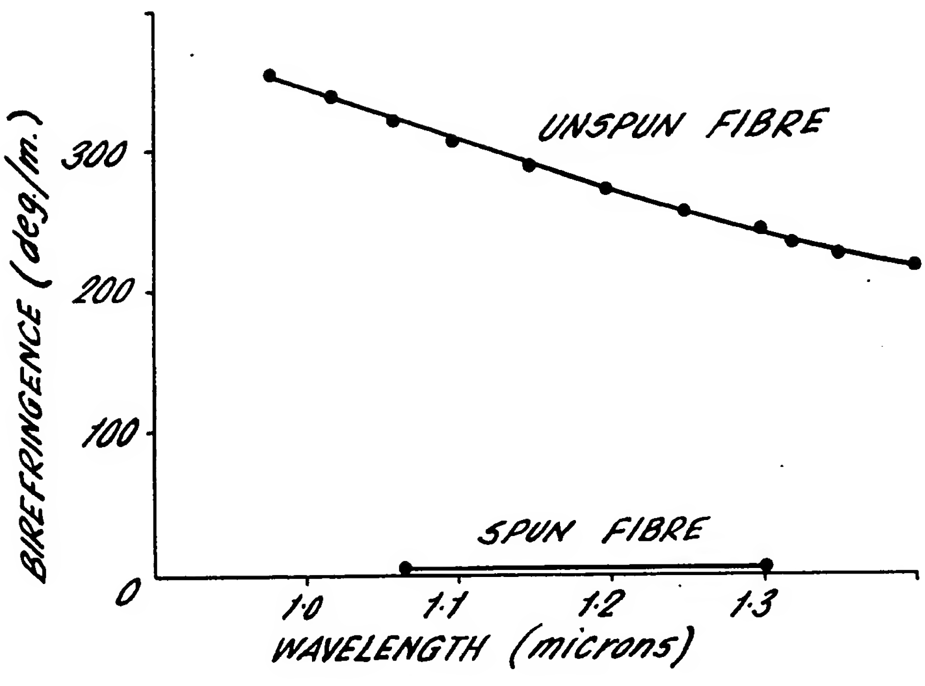

11
10
12
13
17
MEASUREMENT
DIAMETER CONTROL
15
16
18
DRAWING DRUM
SPEED CONTROL

FIG. 2.


UNSPUN FIBRE
SPUN FIBRE
BIREFRINGENCE (deg./m.)
300
200
100
0
1·0
1·1
1·2
1·3
WAVELENGTH (microns)

SPECIFICATION

Optical fibres and their manufacture

This invention relates to optical fibres and their manufacture.

Optical fibres find particular application for the transmission of data and also as sensors. The present invention is concerned with fibres for both these applications.

Considering firstly fibres used as sensors, such devices rely for their operation on modification of the optical wave guide parameters by external means such as pressure or tension or external fields such as magnetic or electrical or acoustic fields. Single mode fibres are of particular interest for this purpose since they ideally have a single, well defined phase velocity and hence polarisation state. It becomes possible therefore to observe small variations in polarisation. Theoretically, a circularly-symmetric, stress-free, straight fibre would be suitable but in practice fibres have a degree of ellipticity which is accompanied by an associated stress asymmetry. The fibre than supports two orthogonally polarised modes with differing phase velocities. The fibre thus appears birefringent and the output state of polarisation will vary cyclically along the fibre length with a period which is dependent on the difference in the propagation constants of the two modes. The length over which one period occurs is known as the polarisation beat length. It is generally found furthermore that the output stage of polarisation is not stable with time because of thermal and mode coupling effects which modify the difference in propagation constants and the power distribution between the modes. The birefringence caused by the core ellipticity is known as form birefringence and the birefringence due to the associated stress asymmetry is known as stress birefringence.

It has been proposed to obtain a more stable linearly polarised output by exciting only one polarised mode in a fibre having very high birefringence such as fibre has been termed "polarisation-maintaining" fibre. For a Faraday effect current transducer however in which the fibre is responsive to an external magnetic field, such an approach is unsuitable since the presence of linear birefringence in the fibre quenches the small Faraday rotation once the fibre length exceeds half the polarisation beat length. Thus the interaction length between the fibre and the magnetic field and hence the sensitivity is very small for a "polarisation-maintaining" fibre with its sub-millimetre beat length. It is preferable therefore to use a low birefringence fibre for a Faraday effect current transducer since the polarisation beat length can be several tens of metres. The latter type of sensor may thus be looped around a large current-carrying conductor to form an ammeter.

In communication systems, the presence of two non-degenerate orthogonally polarised fibre modes can similarly be a disadvantage. The presence of two modes in the fibre can lead to a reduction in bandwidth as a result of a difference in their respective group delays (polarisation mode dispersion). This dispersion is particularly significant in long links, for example of 100 kms or more, as are presently envisaged for some purposes.

Consideration in the past has been given to the use of twisted fibres. It may be shown that the intrinsic fibre linear birefringence is considerably reduced when a fibre is highly twisted (once the local birefringence is averaged along the length of the fibre). However the twisting of a fibre after it has been drawn introduces torsional stresses which result in the introduction of a substantial circular birefringence due to the photo-elastic effect. An optical fibre might be considered as a stack of birefringent plates. If the fibre is twisted, the principal axes of these plates are rotated relative to one another. However in such an analysis, it is necessary to include a photo-elastic effect to allow for the torsional stress and induced circular birefringence that is developed in a fibre twisted after drawing. Thus one has to consider, usig this method of analysis, the fibre as comprising a number of birefringent plates with their principal axes progressively rotated with respect to each other but which are interspersed by optical rotator elements to simulate the photo-elastic effect. An analysis of this nature shows that the state of output polarisation of such a twisted fibre, for a linearly polarised input, will, as one moves along the fibre, oscillate between right and left elliptical polarisation with a simultaneously rotating azimuth. Provided the twist is large relative to the intrinsic fibre linear birefringence, the latter will appear to be quenched, leaving only the twist-induced circular birefringence. In this case, the intrinsic linear birefringence does not affect the sensitivity of the fibre when used as a current monitor. Although a twisted fibre Faraday current monitor has been demonstrated, twisting the fibre after drawing is inconvenient and difficult where a large twist is required and results in residual photo-elastic rotation which is temperature-sensitive.

In a fibre used for communication purposes, it can be shown that twisting reduces the polarisation mode dispersion caused by the intrinsic linear birefringence. However this is offset by the introduction of additional pulse dispersion arising from the wavelength dependence of the photo-elastic coefficient. Twisting the fibre thus reduces the bandwidth limitation due to one effect whilst replacing it with another.

According to one aspect of the present invention, an optical fibre is formed of substantially

torsion-free material with a rate of twist per unit length greater than the intrinsic birefringence. The rate of twist per unit length is preferably at least ten times the intrinsic birefringence.

Considered from another aspect, a method of making an optical fibre comprises drawing the fibre from a heated preform whilst effecting continuous relative rotation between the preform and the drawn fibre. Drawing the fibre from a heated preform enables the twisting to be effected whilst keeping the fibre material substantially unstressed. Such a fibre will be termed hereinafter a "spun" fibre to distinguish it from a twisted fibre, as previously explained, has circular birefringence arising from torsional stress whereas the spun fibre of the present invention has little or no torsional stress and hence circular birefringence.

It is important to distinguish between torsional stresses (which produce circular birefringence) and intrinsic stresses. The latter are generally found in the fibre at all times as a result of the expansion coefficient mismatch which occurs between the silica substrate and coating material. If this stress is asymmetric (as found in a slightly elliptical fibre), it will produce linear birefringence. As will now be shown, the stress-induced linear birefringence can be averaged out by spinning, just as can the form birefringence.

As previously explained, optical fibres in practice are not exactly circular but have an elliptic cross-section. If the fibre is spun during drawing, the azimuth of the asymmetric cross-section precesses along the length of the fibre. The fibre can be considered as composed of individual local sections with alternating birefringence values. Although each section has a relatively high local birefringence, its effect is compensated by the next rotated birefringent section. Because of the absence of the torsional stress in a spun fibre, as distinct from a twisted fibre, one can consider the optical effect as this series of birefringent sections without interspersed rotator sections. The overall effect of a fibre produced in this way is that there is an apparent birefringence which, along the length of the fibre, oscillates between a small positive and a small negative value.

If the rate of twist (which may conveniently be measured in radians per metre) is large compared to the intrinsic form and stress birefringence (which may also be measured in radians per metre) the magnitude of the oscillation becomes negligibly small. Thus the spinning of the preform during drawing greatly reduces the contribution to birefringence due to form and stress asymmetry. Similarly, the time delay between the orthogonal modes caused by polarisation mode dispersion in a conventional unspun fibre is reduced in a spun fibre to a much smaller value, the reduction being by a factor which depends on the spin rate.

Preferably the preform is spun as the fibre is drawn. The spinning is preferably at a rate to give a uniform number of turns per unit length. Conveniently the fibre is drawn at a substantially constant rate and the preform is spun at a substantially constant rate. However it is known in producing optical fibres to control the rate of drawing in order to maintain the fibre diameter constant. In such a technique, the rate of spin may be controlled in accordance with the rate of drawing in order to maintain a uniform twist pitch.

It is not necessary, however, for the spin rate to be constant to achieve the desired result. It could even reverse in direction, e.g. reverse periodically or be random in nature, oscillating from a right-handed to a left-handed twist. Provided the twist rate is, on average, greater than the birefringence, such twisting would reduce the birefringence.

The preform may be produced in any of the known ways, for example, by chemical vapour deposition of the appropriate doped silica materials within a tubular silica substrate. Firstly a cladding material, for example silica doped with B_2O_3, may be deposited followed by chemical vapour deposition of a core material for example silica or a silica doped differently from the core material, e.g. doped with germanium oxide (GeO_2). Such techniques for producing a preform are known in themselves and it is known to produce an optical fibre by drawing from such a preform. To produce the spun fibre of the present invention, the preform may be rotated during the drawing process. The rotational speed depends on the required spin rate and on the rate of drawing. Rotational speeds of up to 2000 r.p.m. have in practice readily been obtained using a tachometer speed controlled d.c. motor with an accurately centred straight preform. At a typical drawing speed of 0.5 m/sec., a spin rate of between 300 and 1500 r.p.m. is required for spin pitches of 10 cm to 2 cm. Much shorter spin pitches, e.g. 2 mm may readily be achieved at reduced pulling speeds. A spun fibre produced in this way may be coated in a known way with a silicone rubber coating or other protective material.

In the following description, reference will be made to the accompanying drawings in which:–

Figure 1 illustrates diagrammatically one technique for making an optical fibre; and

Figure 2 is a graphical diagram showing the relationship between birefringence and wavelength for two different fibres, one made in accordance with the present invention.

A preform from which an optical fibre can be drawn is made in the known way by chemical vapour deposition of a cladding of doped silica, for example B_2O_3 doped silica within a tube of pure silica, followed by deposition of a core, for example a germanium oxide doped silica, within the cladding. Such a technique is described for example in the communication by Norman, Payne, Adams and Smith on pages 309 and 311 of Electronics Letters, 24th May 1979 Vol.

15, No. 11. This preform is shown at 10 in Fig. 1 and is attached to the shaft of a tachometer speed controlled d.c. motor 11 for rotation about its axis. The preform can be centred at its lower end by a guide, for example a spring-loaded diaphragm 12 mounted on an upper port of a pulling furnace 13 having a vertical axis. The fibre is drawn from the lower end of the preform in the known way. After fibre drawing has commenced, the motor is run up to the desired speed. A typical drawing speed of 0.5 m/sec. requires a spin rate of between 300 and 1500 r.p.m. for spin pitches of 10 cm to 2 cm. The fibre is drawn downwardly, as indicated diagrammatically at 15. The diameter of the drawn fibre is measured by measuring means 16 and the drawing speed is controlled automatically, by control means 17, in accordance with the measured diameter to maintain a constant diameter. The motor 11 is also controlled in accordance with the drawing speed so that a constant twist pitch is obtained despite any small variations in drawing speed caused by the automatic control of the diameter.

The drawn fibre may be coated with a silicone rubber coating using known techniques as indicated at 18. It has been found that the coating process and the diameter measurement and control system are not greatly affected by the rotation of the preform.

In the above-described embodiment, the preform is produced by chemical vapour deposition. It can however be made by a number of other known techniques, for example, VAD (vapour axial deposition), OVPO (outside vapour phase oxidation), rod and tube, stratified melt and updraw, ion exchange and the Phasil process. A particularly convenient technique is the double concentric-crucible method of manufacture in which an inner crucible contains the core glass and an outer concentric crucible contains the cladding glass, the fibre being drawn off through a common outlet at the bottom of the crucibles. In this case the double crucible assembly may be rotated but it may be preferred to rotate the tractor assembly.

The effect of spinning on the birefringence properties of a number of fibres is illustrated in the Table below. In the first column of this table, various different fibres are indicated by a fibre number against which is marked the wavelength at which the measurement was made. Measurements of retardation and of rotation are given for four samples of spun fibre. For three of these fibres, measurements are also given for the fibre in the unspun condition. For fibre 319, results are given for two wavelengths.

It will be noted that, for the spun fibres, a reduction in linear retardance, compared with unspun fibres, which approaches two orders of magnitude has been obtained. The birefringence and circular rotation was measured using crossed polarisers and a Soleil compensator, with the fibre suspended vertically in order to reduce the effects of external stresses. Spinning the preform has been found to consistently reduce the birefringence to a level at or below the measurement limit and to introduce no circular birefringence.

The effect of fibre spinning on polarisation mode-dispersion was measured by determining the variation of fibre polarisation properties with wavelength. Raman generation in a single-mode fibre pumped with a Q-switched Nd:YAG laser was used as a tunable-wavelength source and the birefringence $\Delta\beta$ and rotation in the test fibre measured as above. A typical result is shown in Fig. 2 (upper curve) for an unspun fibre. The polarisation mode-dispersion

$$\Delta\tau = \frac{z}{c} \; \frac{d(\Delta\beta)}{dk}$$

is estimated by fitting a curve to the data points and taking the derivative with respect to wavelength.

In the case of the spun fibre the birefringence and rotation was at the limits of detection and consequently only two points are shown on the lower curve in Fig. 2.

The intrinsic polarisation mode-dispersion at a wavelength of 1.2μm was calculated to be 4.6 ps/km for the unspun fibre and less than 0.02 ps/km for the spun fibre, this illustrating the large reduction possible with the spinning technique.

Analysis has shown that spun fibres are as sensitive as conventional low birefringent fibres to the Faraday effect and, furthermore, are not expected to exhibit significant polarisation variation with temperature. Low birefringence fibres are difficult to manufacture reproducibly and the spun fibre technique provides a simple alternative enabling reproducible fibres to be obtained which are suitable for use in a Faraday effect current transducer. In fibres of data transmission, the spinning ensures that the residual polarisation mode-dispersion is reduced to a negligible value and thus such fibres are attractive for long unrepeated links.

TABLE

FIBRE NUMBER		UNSPUN FIBRE	SPUN FIBRE	FIBRE SPIN PITCH
337	retardation	450°/m.	2.3°/m	5.0 cm.
(633 nm)	rotation	~50°/m.	~0°/m	
302	retardation	60°/m.	<1°/m.	1.0 cm.
(633 nm.)	rotation	4.3°/m.	~0°/m	
333	retardation	-	<2°/m.	3.9 cm.
(1064 nm.)	rotation	-	~0°/m	
319	retardation	232°/m	<4°/m.	0.92 cm.
(1064 nm.)	rotation	1.1°/m.	0.4°/m.	
319	retardation	208°/m.	~4°/m.	0.92 cm.
(1300 nm.)	rotation	4°/m.	0.6°/m.	

CLAIMS

1. An optical fibre of substantially torsion-free material with a rate of twist per unit length greater than the intrinsic birefringence.
2. An optical fibre as claimed in claim 1 wherein the rate of twist per unit length is at least ten times the intrinsic birefringence.
3. A method of making an optical fibre comprising drawing the fibre from a heated preform whilst effecting continuous relative rotation between the preform and the drawn fibre.
4. A method as claimed in claim 3 wherein the rate of rotation is such that the rate of twist per unit length of the drawn fibre is greater than the intrinsic birefringence.
5. A method as claimed in claim 3 wherein the rate of rotation is such that the rate of twist per unit length is at least ten times the intrinsic birefringence.
6. A method as claimed in any of claims 3 to 5 wherein, to effect the relative rotation, the preform is spun as the fibre is drawn.
7. A method as claimed in any of claims 3 to 6 wherein the spinning is at a rate to give a uniform number of turns per unit length.
8. A method as claimed in any of claims 3 to 7 wherein the fibre is drawn at a substantially constant rate and the preform is spun at a substantially constant rate.
9. A method as claimed in any of claims 3 to 7 wherein the rate of drawing is controlled to maintain the fibre diameter constant and wherein the rate of spin is controlled in accordance with the rate of drawing.
10. A method as claimed in any of claims 3 to 9 wherein the preform is produced by chemical vapour deposition of glass materials within a tubular silica substrate.
11. A method of making an optical fibre substantially as hereinbefore described with reference to the accompanying drawings.
12. An optical fibre made by the method of any of claims 3 to 11.

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